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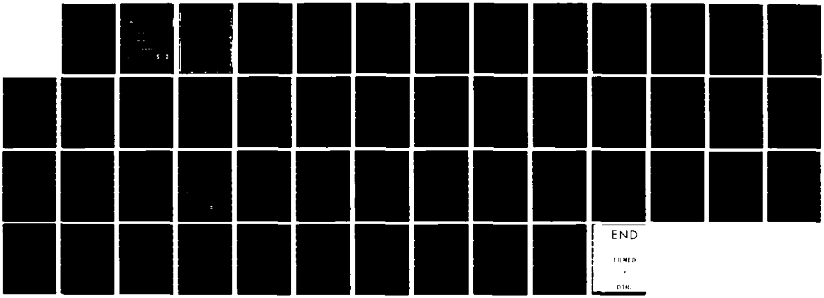

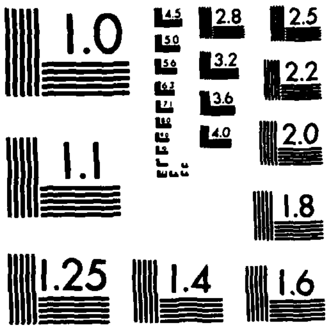

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CIVIL ENGINEERING

TRACKAGE

DESIGN MANUAL 5.6

DEPARTMENT OF THE NAVY
NAVAL FACILITIES ENGINEERING COMMAND
200 STOVALL STREET
ALEXANDRIA, VA. 22332

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Ballast and sub-ballast; highway grade crossing; railroad bridges and tressles; railroad trackage; roadway; scales; ties; track; trackage in pavement; warehouse trackage; yards.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Design criteria are presented for use by qualified engineers in designing naval facility trackage for both railroads and wide gage portal cranes. Criteria for railroad trackage include those for roadbeds, ballast, ties, rails, track grade, turnouts, crossovers, highway crossings, sidings, warehouse trackage, track scales, and yards; those for portal crane trackage cover rails, rail supports, turnouts, crossings, alinement, components, curves, and design procedures.

ABSTRACT

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FOREWORD

This design manual is one of a series developed from an evaluation of facilities in the shore establishment, from surveys of the availability of new materials and construction methods, and from selection of the best design practices of the Naval Facilities Engineering Command (NAVFACENGCOM), other Government agencies, and the private sector. This manual uses, to the maximum extent feasible, national professional society, association, and institute standards in accordance with NAVFACENGCOM policy. Deviations from these criteria should not be made without prior approval of NAVFACENGCOM HQ (Code 04).

Design cannot remain static any more than can the naval functions it serves or the technologies it uses. Accordingly, recommendations for improvement are encouraged from within the Navy and from the private sector and should be furnished to NAVFACENGCOM HQ, Code 04. As the design manuals are revised they are being restructured. A chapter or a combination of chapters will be issued as a separate design manual for ready reference to specific criteria.

This publication is certified as an official publication of the Naval Facilities Engineering Command and has been reviewed and approved in accordance with SECNAVINST 5600.16.

W. M. Zobel
Rear Admiral, CEC, U. S. Navy
Commander
Naval Facilities Engineering Command

CIVIL ENGINEERING DESIGN MANUALS

DM NO.	Superseded Chapters in Basic DM-5	TITLE
5.1	1	Surveying
5.2	2	Hydrology and Hydraulics
5.3	3	Drainage Systems
5.4	4	Pavements
5.5	5	General Provisions and Geometric Design for Roads, Streets, Walks, and Open Storage Areas
5.6	6&7	Trackage
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CHAPTER 1. RAILROAD TRACKAGE

Section 1. STANDARDS AND CRITERIA

1. SCOPE. This chapter covers criteria for the design of naval facility trackage. Included are roadways, ballast, ties, rails, track grade, turnouts, crossovers, highway crossings, sidings, warehouse trackage, track scales, and yards. For portal crane trackage, see Chapter 2 of this manual.

2. DESIGN CRITERIA USAGE. The criteria presented herein are applicable to the design of new trackage and for major rehabilitations. Where conditions will not permit their use prior approval is required from NAVFACENGCOM HQ. Requirements for maintenance, minor repair, and replacement of existing trackage, which is being successfully used, are presented in other appropriate NAVFAC Maintenance Manuals and instructions and are not required to be in accordance with these design criteria.

3. CANCELLATION. This manual, Trackage, NAVFAC DM-5.6, cancels and supersedes NAVFAC DM-5.6 of October 1979 and changes 1, Mar. 80, and 2, Mar. 81.

4. RELATED CRITERIA. For criteria related to railroad trackage but appearing elsewhere in the Design Manual series, see the following sources:

Subject	Source
Hydrology and Hydraulics	NAVFAC DM-5.2
Drainage Systems	NAVFAC DM-5.3
Waterfront Operational Facilities.	NAVFAC DM-25.1
Rail supports (deck fittings)	
Trackage location and arrangement on waterfront structures (deck structure design)	

5. POLICY. When planning track layouts, railroad trackage should be separated, wherever possible, from portal crane trackage because, apart from the similarity of the rails, the requirements for portal crane trackage are completely different from railroad trackage.

a. Where Separation is Possible. Provide separation to insure:

(1) Maximum efficiency of both types of trackage.

(2) Elimination of switching hazards.

(3) Free passage of rolling stock under cranes.

b. Where Separation is Impossible. Where both cranes and rolling stock utilize a common rail, the other railroad rail shall be placed between the crane rails.

6. RAILROAD TRACKAGE STANDARDS. Standards in railroad trackage design appear in: (1) American Railway Engineering Association (AREA) Manual for Railway Engineering, current edition; (2) AREA Portfolio of Trackwork Plans, current edition (companion volume to AREA Manual for Railway Engineering); and (3) Military Standards (MIL-STD) as listed. State and local regulations should be observed where practicable.

a. The AREA Manual is revised annually and the user shall refer to the current edition, which can be verified by contacting the AREA at: 2000 L Street, N.W., Washington, D.C. 20036. Manual owners receive revision notices yearly. AREA references in this chapter of NAVFAC DM-5.6 are keyed to the 1980-1981 AREA Manual.

7. RAILROAD CAR CURVATURE STANDARDS. Minimum curvature negotiability standards for railroad cars appear in Section 2.1, Design Data, Association of American Railroads (AAR) - Mechanical Division, Specifications for Design, Fabrication and Construction of Freight Cars, Volume 1, current edition.

8. FEDERAL RAILROAD ADMINISTRATION (FRA) TRACK SAFETY STANDARDS. The Code of Federal Regulations (CFR) Title 49 Part 213 - Track Safety Standards prescribe minimum safety standards which may be used by maintenance personnel. Under these standards tracks are classified as 1, 2, 3, 4, 5, or 6 wherein the maximum allowable speed limits for freight and passenger trains are assigned to each class. If a segment of track does not meet all the conditional requirements for its intended class it is classified to the next lowest class for which it does meet all the requirements. The FRA Track Safety Standards "prescribes initial minimum safety requirements for railroad track" and shall be used for safety inspections only. They are not to be used for design purposes or as construction inspection criteria.

Section 2. ROADWAY

1. WIDTH. Provide a minimum of 18 inches from the toe of the ballast to the edge of the finished grade. (See AREA Manual, Chapter 1, Part 1.2, Design, current edition.)

a. Cut Sections. Provide a minimum of 9 feet from track centerline to the shoulder line.

b. Fill Sections. Provide a minimum of 11 feet from track centerline to the shoulder line.

c. Minimum Cut Dimensions. Consideration is to be given to drainage, snow removal, debris removal, rock falls, and maintenance. (See AREA Manual, Chapter 1, Part 1.2, Design, current edition.)

2. SLOPES AND SUBGRADE. Slope and subgrade criteria are as follows: (See AREA Manual, Chapter 1, Part 1, Roadbed, current edition.)

a. Cut and fill slopes shall be designed according to a slope stability analysis unless adequate local experience has shown a particular slope to be stable.

b. Subgrade. For subgrade criteria, see AREA Manual, Chapter 1, Part 1, Section 1.2.5, Roadbed and NAVFAC DM-7, Soil Mechanics, Foundations, and Earth Structures, current edition. Subgrade cross slopes shall be 48 horizontal to 1 vertical. The subgrade shall slope in one direction beneath a single track and shall be crowned between tracks for multiple tracks. In no case shall the crown of the subgrade occur under the ties.

3. DRAINAGE. Water is a principal influence on soil stability in roadbed, subgrade, and slopes. Control of surface and subsurface water is one of the most important factors in railroad design. For design guidance, see AREA Manual, Chapter 1, Part 1, Section 1.2.4, Drainage; Part 3, Natural Waterways, Part 4, Culverts, current edition; NAVFAC DM-5.2, Hydrology and Hydraulics; and DM-5.3, Drainage Systems.

4. MONUMENTS. Right-of-way monuments should be reinforced concrete posts (or similar) 6 inches square, 4 feet long, and embedded 3 feet in the earth. The specification for monuments from the Department of Transportation in the state where the work is being done may be used where appropriate.

Section 3. BALLAST AND SUB-BALLAST

1. ECONOMICS. Select ballast and sub-ballast with due consideration of cost and availability.

2. SPECIFICATIONS AND APPLICATIONS. (See AREA Manual, Chapter 1, Part 2, Ballast, current edition, for material specifications.) The following materials are acceptable in order of quality as listed:

(1) Crushed stone.

(2) Crushed slag.

(3) Prepared gravel.

(4) Pit run gravel.

(5) Cinders.

(6) Other local materials may be used temporarily or in an emergency.

3. DEPTH. The combined thickness of ballast and sub-ballast required for a given axel load and subgrade strength should be determined on basis of engineering calculation and experience. A minimum of 8 inches of ballast under the ties and 6 inches of sub-ballast shall be provided. A minimum of 12 inches of ballast under the ties and 6 inches of sub-ballast in main running tracks should be provided. The design strength of the subgrade shall not be exceeded by the traffic load. (See AREA Manual, Chapter 1, paragraph 1.2.5.4, Ballast Thickness, current edition.)

4. CROSS SECTION DIMENSIONS. (See AREA Manual, Chapter 1, Part 2, Ballast, current edition.)

5. SHRINKAGE ALLOWANCE. (See AREA Manual, Chapter 1, Part 2, Ballast, current edition.)

Section 4. TIES

1. SPECIFICATIONS AND APPLICATIONS. Ties may be of wood, concrete, or other material.

a. Wood Ties. All wood ties shall conform to Federal Specification MM-T-371 (latest revision), Ties, Railroads, Wood (Cross and Switch) and have protective treatment.

b. Concrete Ties. (See AREA Manual, Chapter 10, current edition.)

c. Ties of Other Materials. Consider other materials such as steel in place of wood or concrete ties when practicable.

2. ECONOMIC SERVICE LIFE AND TESTS. (See AREA Manual, Chapter 3, Part 3, Tie Tests and the Economics of Service Life, current edition.)

3. HANDLING AND PROTECTION OF TIMBER TIES. To prolong the life of protected ties, adopt the following practices:

(1) Use steel tie plates under the rails.

(2) Treat all cut surfaces with preservative.

(3) Use care in handling with sharp-pointed tools to avoid damage.

(4) Fill empty spike or bolt holes by driving treated wooden plugs into the holes. (See AREA Manual, Chapter 3, Part 1, Timber Cross Ties, current edition.)

For additional information, refer to AREA Manual, Chapter 3, Part 5, The Handling of Ties From the Tree into the Track, current edition.

4. DIMENSIONS. Use the following dimensions:

a. Cross Ties. For running track cross ties of 7 inches by 8 inches or 7 inches by 9 inches by 8 feet 6 inches long should be used. For yards and sidings, 6 inches by 8 inches by 8 feet 0 inches long may be used.

b. Timber Switch Ties. Should be the same cross section as adjacent cross ties. (See AREA Manual, Chapter 3, Part 2, Timber Switch Ties, current edition and Federal Specification MM-T-371 (latest revision).)

c. Bridge or Trestle Ties. Shall conform in spacing and length to the bridge or trestle design. (See AREA Manual, Chapter 7, current edition.)

5. TIE SPACING. Use the following spacing:

a. Running Track. Use 24 ties per 39-foot rail.

b. Yards and Sidings. Use 20 ties per 39-foot rail.

c. Switches and Crossovers. For switches and crossovers, follow AREA Portfolio of Trackwork Plans, current edition.

Section 5. TRACK

1. RAIL SPECIFICATIONS. Choose sections conforming to AREA recommended sections. Use 115 RE rail for new construction and major rehabilitation projects unless quantities of larger sizes are stockpiled. For minor replacement or repair work match existing size rail where adequate.

a. Material. Rails shall be manufactured to specifications for hydrogen eliminated standard rail steel as recommended in the AREA Manual, Chapter 4, Rail, Part 2, Specifications, current edition.

b. Rail Drilling. Rails shall be drilled according to AREA Manual, Chapter 4, Rail, Part 1, Design, Table 1, Recommended Rail Drillings, Bar Punchings and Track Bolts, current edition, for new construction and major rehabilitation projects. For minor replacement or repair work, match existing where adequate.

c. Curved Rail. Where conditions are such that curves of 20 degrees (288-foot radius) or more are absolutely necessary, rails should be pre-bent to the design radius prior to installation.

2. GAGE. For straight track and curves up to 12 degrees (478-foot radius) use a gage of 4 feet 8-1/2 inches measured between the inside heads of rail 5/8 inch below the top of rail. For curves greater than 12 degrees (478-foot radius) widen gage 1/8 inch for each additional 2 degrees (except through turnouts) to a maximum allowable of 4 feet 9 inches.

3. SPIKES. Use 6-inch cut spikes conforming to specifications as recommended in the AREA Manual for Track Spikes, including 0.20 percent copper, Soft-Steel or High Carbon, Chapter 5, Part 2, Spikes, current edition. The smaller 5-1/2-inch cut spike may be used in sidings where 6-inch by 8-inch cross ties are used.

a. Holes Bored for Spikes. For size, see AREA Manual, Chapter 3, Part 1, Timber Cross Ties, current edition.

b. Use two spikes per tie plate on tangent track and curved track with not more than 6 degrees of curvature (radius 955 feet or larger). On curved track with not more than 6 degrees of curvature that has some superelevation and heavy loads operating at slow speeds use three spikes per tie plate. Use three spikes per tie plate on curved track with more than 6 degrees of curvature (radius 955 feet or less). Use four spikes per tie plate where traffic, curvature, speed, and superelevation indicate a need, with care being taken to minimize "spike killing" of the tie (i.e., weakening of a tie where spike holes are too close together).

4. TIE PLATES. Use tie plates conforming to specifications for hot-worked, high-carbon steel tie plates including 0.20 percent copper. For size and material, see AREA Manual, Chapter 5, Track Part 1, Tie Plates, current edition.

5. RAIL JOINT SPACING. Rail joint spacing shall be provided to insure space for expansion of the rail as specified in AREA Manual, Chapter 5, Part 5, Track Maintenance, current edition.

6. RAIL JOINT BAR. Use high carbon-steel, head-free, head-eased sections as per AREA Manual, Chapter 4, Part 1, Design and Part 2, Specifications, current edition. For bar punching pattern and application, see reference in Section 5, Paragraph 1.b.

7. BOLTS AND NUTS FOR RAIL JOINT BAR. Use oval neck, heat-treated, carbon steel track bolts and carbon-steel nuts as per "AREA Manual," Chapter 4, Part 1, Design and Part 2, Specifications, current edition. For bolt size and application, see reference in Section 5, paragraph 1.b.

8. SPRING WASHERS. Use washers conforming to specifications as recommended in the AREA Manual, Chapter 4, Part 2, Specifications for Spring Washers, current edition.

9. RAIL ANCHORS. Use a one-piece anchor. Anchors shall be used on grades to restrain rail movement in the predominant direction of traffic and to resist temperature expansion. Anchors shall be applied in pairs on opposite rails so that they both bear against either the tie or tie plate. Anchors shall be uniformly distributed along the rail without application on joint ties. (See AREA Manual, Chapter 5, Part 5, Track Maintenance, current edition.)

10. RAIL GAGE RODS. To prevent rail spread and overturning on curves over 10 degrees (574-foot radius) adjustable gage rods (for standard or widened gage) may be used. Gage rods shall not be used as a substitute for competent ties.

11. RAIL BRACES. Use braces on rails subject to overturning and, if required, on outside rails on curves of 20 degrees (238-foot radius) or more.

12. GUARDRAILS. Use guardrails as follows:

(1) Opposite the frog point for protection, except for self-guarded frogs.

(2) Where derailment is likely.

(3) Where derailment would be hazardous or costly, such as on steep embankments and bridges.

a. Gaging. For gaging, see AREA Portfolio of Trackwork Plans, Plan No. 791.

b. Material. Relay rail of the same size as the running rail may be used if it is in good condition.

13. TRACK CONSTRUCTION. Use specifications as recommended in the AREA Manual, Chapter 5, Part 4, Track Construction, current edition.

Section 6. RUNNING TRACK GRADE AND ALIGNMENT

1. GRADIENT. Track gradients are determined by the cost of construction versus the operating costs. Naval facility trackage is usually located in level terrain where gradient problems are non-existent or minimal. Maximum design gradients should not exceed 3 percent compensated. Steeper gradients, only up to 5 percent compensated, shall be approved by NAVFACENGCOM. If a connecting railroad is to operate over Naval facilities, discussions with the railroad should take place during the design phase regarding gradients. (See AREA Manual, Chapter 16, current edition.)

2. CURVES. The type and character of equipment that must negotiate the curves, available right of way, desired operating speed and traffic density shall be considered in determining track curvature. The chord definition for curves shall apply for railroad track.

a. Ruling Radii, Horizontal. For design of new tracks and for major track rehabilitation the minimum radius shall be 350 feet. If a radius smaller than 350 feet is required because of space limitations, prior approval must be obtained from NAVFACENGCOM HQ. Larger radii, especially over 600 feet, are desirable and every reasonable effort shall be made to achieve such radii. A spiral curve is desirable between tangents and curves and between the different radii of compound curves on all tracks. Spirals shall be according to AREA Manual, Spiral Curves Chapter 5, Part 3, current edition.

b. Reverse Curves. The minimum allowed tangent distance between reverse curves, including crossovers, shall be according to the AREA Manual, Chapter 5, Part 3, Reverse Curves, current edition. The desirable tangent distance between reverse curves in yards and terminals should be 100 feet or more.

3. SUPERELEVATION. Superelevation is generally not required on tracks used at low speeds, i.e., in yards and sidings. Where required, superelevation shall be computed per AREA Manual, Chapter 5, Part 3, Elevations and Speeds for Curves, current edition. Railroad track shall not be superelevated where common with crane track.

4. TRACK CENTERLINE SPACING. Between parallel running tracks, 14 feet shall be provided.

5. CLEARANCES. Clearance (horizontal and vertical) shall be in accordance with Plates B, B-1, C, C-1, D, E, and F in AAR Supplement to Manual of Standards and Recommended Practices, current edition which is reproduced in the National Railway Publication Railway Line Clearances, current edition. Clearance of fixed obstructions shall be in accordance with AREA Manual, Chapter 28, current edition.

Section 7. TURNOUTS AND CROSSOVERS

1. TURNOUTS. The geometry of the turnout is governed by the size of the frog. Where commercially owned and operated switching equipment is used, turnouts shall meet the minimum requirements of the connecting railroad and MIL-STD-615, Turnout, Railway, with Bolted Rigid Frog, latest edition. Where Navy owned and operated switching equipment is used, turnouts shall be in accordance with MIL-STD-615 and No. 8 frogs should be used. If a smaller than a No. 8 frog is required because of space limitations, No. 7, No. 6, or No. 5 frogs may be used with caution. Spring rail frogs shall not be used.

2. CONNECTING CURVES. Connecting curves should have radii greater than the lead curve.

3. CROSSOVERS. Criteria for crossovers are given below.

a. Description. Crossovers consist of two turnouts from adjacent tracks, connected by a tangent or by reversed curves with a tangent between, placed between the ends of the frogs.

b. Reverse Curves. Consider reverse curves only because of space limitations.

4. TURNOUT LOCATION. No part of the turnout shall be located on a vertical curve.

Section 8. HIGHWAY GRADE CROSSING

1. WIDTH OF CROSSING. Crossing widths shall be 4 feet wider on each side than adjacent roadway surface measured at right angles to the highway or as prescribed by local law.

2. PROFILE OF CROSSINGS. The surface of the highway shall be in the same plane as the top of the rails for a distance of 2 feet outside of the rails. The top of the rail plane shall be connected with the gradeline of the highway, each way, by vertical curves which satisfy highway requirements for riding conditions and sight distances.

3. MATERIALS FOR CROSSING. Materials used are as follows: (See AREA Manual, Chapter 9, Part 1, Highway-Railway Grade Crossings, current edition.)

a. Heavily Traveled Roads. Prefabricated rubber, precast concrete, prefabricated treated timber, or sectional treated timber shall be used. Welded rails should be used through the crossing.

b. Lightly Traveled Roads. Treated wood plank or bituminous pavement shall be used.

4. SIGN, SIGNALS, AUTOMATIC CROSSING GATES, AND FLOODLIGHTING. (See AREA Manual, Chapter 9, current edition.)

Section 9. TRACKAGE IN PAVEMENT

1. HIGHWAY GRADE CROSSING. (See Section 8.)

2. SPECIFICATIONS. Trackage in pavement shall be avoided where practicable. Where unavoidable it should be built as follows: for light to medium traffic conditions the track can be in flexible pavement (ballast, timber ties, and bituminous pavement); and for heavier applications rails set in a rigid pavement should be used. New 115 RE or heavier rails shall be used in all pavement installations. Welded rails should be used through heavily used crossings.

a. Bituminous Pavement. 7 inches x 9 inches x 8 feet-6 inches creosoted cross ties on 19-1/2-inch centers should be used and provide a minimum of 12 inches of well compacted ballast below the ties and in the tie cribs (space between the ties). Care shall be taken to maintain uniform bearing throughout the length of each tie. The bituminous paving material shall be applied in multiple layers with a 3-inch wide by 2-1/2-inch deep flangeway formed on the gage side of each rail.

b. Concrete Pavement. For new construction or major rehabilitation track constructed in concrete, pavement should be built according to the details in Figure 38, Railroad Track Support in NAVFAC DM-25.1, Piers and Wharves. Flangeways shall be 2-3/4 inches wide by 2-1/4 inches deep on the gage side of each rail. A gage rod may be substituted for the 3/4-inch diameter tie rod shown in Figure 38.

3. TURNOUTS. Switches or frogs should not be installed in paved areas. Where unavoidable tongue and mate switches as per AREA Portfolio of Trackwork Plans, current edition, should be used.

Section 10. SIDINGS

1. TRACK CENTERLINE SPACING. Between parallel siding tracks 14 feet shall be provided. Between parallel and mainline tracks 15 feet shall be provided.

2. MINIMUM TANGENT DISTANCE. For the minimum tangent distance in a reverse curve, see Section 6, paragraph 2.c. of this manual.

3. GRADIENTS. Level or non-rolling gradients are most desirable. If necessary, a maximum of up to 1.5 percent may be used.

4. TRACK ENDS. Track ends shall be provided with stops or bumpers as follows, based on cost and traffic density:

(1) Commercially available fabricated stops.

(2) A timber fastened across the rails.

(3) A pile of sand dumped over the track end.

Section 11. WAREHOUSE TRACKAGE

1. GRADIENT APPORTIONMENT. The gradient shall be apportioned to make certain that:

(1) The maximum gradient along warehouse loading platforms shall be 1 percent.

(2) The maximum gradient along tracks between individual warehouses shall be 3 percent for short distances.

(3) Crossovers shall not be located on the 3-percent gradient where long trains of cars will be pushed upgrade through the crossovers.

2. HORIZONTAL AND VERTICAL CLEARANCES. For clearances to fixed obstructions such as walls, doorways, and platforms, see Section 6, paragraph 5 of this manual and local servicing railroad.

3. WAREHOUSE RAILROAD LAYOUT. For warehouse railroad layout, see Definitive Designs for Naval Shore Facilities, NAVFAC P-272.

Section 12. TRACK SCALES

1. SCALES. There are two types of scales available for weighing cars. (See AREA Manual, Chapter 34, current edition.)

a. Static Scale. One car at a time is rolled onto the scale, stopped, and weighed. The scale usually is a beam ballance type, but can be a load cell type.

b. Weigh-in-Motion Scale. This scale weighs cars coupled together while being pulled over the scale by a locomotive at slow speed. The scale is a load cell type.

2. SELECTION. If a scale is necessary, a static scale would probably meet Navy needs. Weigh-in-motion scales are sophisticated devices used where large numbers of cars are to be weighed each day.

3. LOCATION. Scales shall be located to minimize switching.

4. ALIGNMENT. A minimum of 100 feet of tangent tracks shall be provided on scale approaches. Gradients should be less than 0.05 percent over a static scale. Weigh-in-motion scale tracks should be level or slightly upgrade allowing the train to be stretched during weighing.

5. DEAD RAILS. Where a by-pass track cannot be built around the scale, use dead rails to gauntlet equipment not to be weighed over the scale.

Section 13. YARDS

1. SCOPE. Yards are places for the storage and sorting of railroad cars. A freight terminal can also be a railroad yard. Larger yards usually include car and locomotive service and maintenance facilities. Background data for design and layout of yards can be found in the AREA Manual, Chapter 14, current edition, and shall be used as a guide for new construction and major rehabilitation.

2. GENERAL CONSIDERATIONS. Features of a more general nature are discussed as follows:

a. Fire Protection. Hydrants with hose houses shall be located to comply with applicable codes and regulations. Chemical extinguishing systems shall be installed where appropriate to protect against oil and electric fires.

b. Theft and Vandalism. Protective measures shall be carefully considered in the design of yards.

c. Efficiency. Yards shall be designed for efficient switching and handling tasks and to minimize delays and demurrage charges.

d. Expansion. Yard layouts shall provide for anticipated future expansion so that the number and length of tracks in them may be increased as required with minimum interference to operation or minimum relocation of existing trackage.

e. Track Capacity. In computing car capacity a minimum of 50 feet per car shall be used for all tracks other than those to be used for special equipment.

f. Yard Lighting. Where necessary lighting should be installed following the recommendations of the AAR Engineering Division Committee on Electrical Facilities - Fixed Property.

g. Drainage. An adequate drainage system is essential and shall be installed so that it can be easily cleaned and maintained.

h. Communications. Facilities such as teletype, pneumatic tube systems, loud speakers, talkback, paging systems, television, telephones, and radios shall be considered to expedite operations.

3. TRACK ARRANGEMENTS. Main tracks should not pass through a yard, but should be connected to yard tracks as directly as practicable. Crossovers to facilitate all normal and regular movement in the yard, with minimum interference between the different movements, shall be provided.

a. Body Tracks. A series of parallel tracks which could be part of a storage, repair, receiving, departure, classification, or departure yard shall have a minimum of 14 feet between centers. Where a body track parallels a main or important running track, a minimum of 20 feet between centers shall be provided, subject to state regulations on clearances. (See AREA Manual, Chapter 28, Part 3, Section 3.6, Legal Clearance Requirements by States, current edition.)

b. Ladder Tracks. At one or both ends of the body tracks, there is a diagonal track which is called the ladder track which connects the body tracks to a main or running track. The angle the ladder track makes with the body track should equal the frog angle. Where space is a problem, tandem ladder tracks, with angles twice or triple the frog angle, should be used. Ladder tracks shall have a minimum of 15 feet between centers from other tracks. Parallel ladder tracks shall have a minimum of 20 feet between centers.

4. GRADIENTS. Wherever practicable, gradients should be level on tracks used for standing of cars. Maximum yard gradients shall not exceed 1.5 percent without prior approval of NAVFACENGCOM.

Section 14. RAILROAD BRIDGES AND TRESTLES

1. DESIGN. A request for permission to construct bridges over navigable waters shall be forwarded to NAVFACENGCOM HQ for endorsement to the Coast Guard, U.S. Department of Transportation. Use AREA Manual, Chapters 7, 8, and 15, current edition, respectively for design of Timber Structures, Concrete Structures and Foundations, and Steel Structures.

CHAPTER 2. WIDE GAGE PORTAL CRANE TRACKAGE

Section 1. CRITERIA AND TYPES

1. SCOPE. This chapter presents design criteria and standards for trackage for different types of wide gage portal cranes. Particular reference is made to rails, rail supports, turnouts, crossings, alinement, components, curves of all types, and design procedures. The criteria herein cover design of both new trackage and rehabilitation alinements. NAVFACENGCOM HQ has computer programs available for new track design analysis and rehabilitation design and analysis.

2. RELATED CRITERIA. Certain criteria, related to portal crane trackage, appear elsewhere in this DM series. See the following sources:

Subject	Source
Waterfront Operational Facilities	NAVFAC DM-25
Rail supports (deck fittings)	
Trackage location and arrangement (deck structure design)	
Wheel loads (wheel loads for locomotive and portal cranes)	
Weight Handling Equipment and Service Craft	NAVFAC DM-38
Design details (weight and line handling equipment)	

3. POLICY. Portal crane trackage should be separate from railroad trackage, except as stated in Chapter 1, and in NAVFAC DM-25.

4. TYPES OF PORTAL CRANE TRACKAGE. There are two types of portal crane trackage systems in use in the Naval Shore Establishment.

a. Two-Rail System. The cranes for this system are equipped with double-flanged wheels. This is the preferred track system.

b. Four-Rail System. This system consists of two standard (RR) gage tracks. The cranes for this system are equipped with single-flanged wheels. This system is the most expensive and interferes with railroad service.

Section 2. TRACKAGE COMPONENTS

1. RAILS. The rail section for new track and for extensive rail replacement projects shall conform to 135-pound control-cooled CR (crane rail) standard. For locations and arrangements of portal crane trackage and rail supports, see sources under related criteria above. Use welded joints wherever possible.

2. TURNOUTS AND CROSSINGS. A turnout is an arrangement of switches and a frog, by means of which the crane is diverted from one track to another. For standard switch details, see NAVFAC Standard Drawings. Standard switched shall be used on all new construction and only on level grade.

a. Frogs (Two-Rail Track System).

(1) Rigid Frogs. The use of rigid frogs is permissible only in cases where the actual frog angle is greater than that shown in Figure 1 for the actual crane rail radius. They shall be designed for double-flanged wheels.

(2) Turntable Frogs. This type of frog is preferable for all locations, and its use is mandatory in accordance with Figure 1.

(3) Material. Use only cast manganese steel.

(4) Wheel Loads. See "Wheel Loads for Locomotive and Portal Cranes" in NAVFAC DM-25.

b. Frogs (Four-Rail Track System).

(1) Rigid Frogs. Design for single flanged wheels.

(2) Material. Use only cast manganese steel.

(3) Wheel Loads. See "Wheel Loads for Locomotive and Portal Cranes" in NAVFAC DM-25.

c. Special Crossing. Use only cast manganese steel, and use on level grade only.

Section 3. PORTAL CRANE TRACK CURVE ALINEMENT

1. APPLICATIONS. Apply the design procedure outlined in this section to:

(1) All new curved portal crane track projects.

(2) Curved extensions to existing crane trackage.

(3) Rehabilitation projects where new track foundations are required throughout a curve.

Rehabilitation design for curved trackage on existing foundations will have different methods of calculation than are outlined in this section. Some of the criteria laid down for new track cannot be applied to rehabilitation projects because of the need to fit the track on the existing foundation while meeting gage reduction requirements; however, wherever possible, the definitions and objectives of this section should be utilized for replacement design. Criteria for rehabilitation design of curved track on existing foundations are laid out in Section 4 of this Chapter.

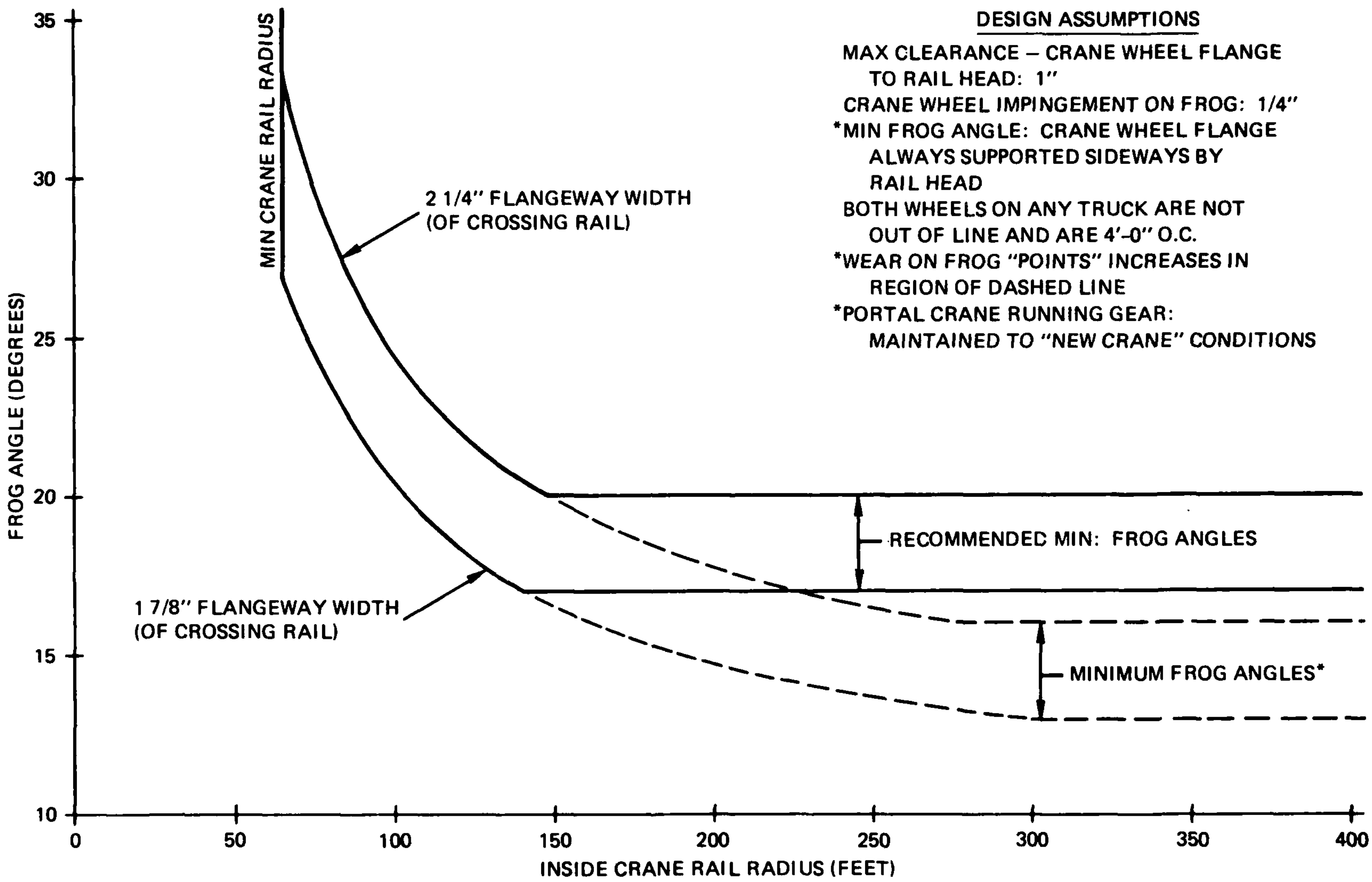

FIGURE 1
Minimum Rigid Frog Angle—Portal Crane Rails

a. Problem Description. The track gage must be reduced on curves because of the nonradial position of the ends of the crane (See Figure 2). Some form of transition is required between the tangent track and the short-radius curved track.

(Note: A new design that has been made to meet this condition can be analyzed for crane float and track gage conditions by NAVFACENGCOM HQ computer program entitled TRACKS.)

2. REDUCED GAGE. Actual gage reduction for a given radius may be computed precisely, but as the crane frame covers or "straddles" a number of radii in transversing the transition curve, the gradual reduction between the tangent gage and the gage at the end of the transition curve is an approximation. The shorter the radius the greater the gage reduction required. Gage reduction on curves with a radius greater than 300 feet is normally not required, as it is well within the float capability of most cranes.

3. CRANE EQUIVALENT LENGTH. Equivalent length is the length of a theoretical crane that has its corners riding over the centerline of the rails when all the wheels of the actual crane are on the rails of the curve. See Figure 2.

4. LATERAL FLOAT. Lateral float is the amount of transverse movement possible on the gudgeon pins of the crane (See Figure 3). No transition from tangent to curve or vice versa has been designed to eliminate the necessity for providing some lateral floating action in cranes.

a. Radius. The floating action (transverse movement) provided in cranes permits a crane to traverse a large radius curve without any gage reduction. Normally the float capability of a crane is such that a curve of 300 feet radius can be traversed with a safety factor greater than two and without a gage reduction.

b. Minimum Radius. It is desirable that the radius of the central portion of the curve be not less than 80 feet, except where extreme space limitations force this condition.

c. Float for New Cranes. Prior to purchase of new cranes, the existing track system is to be investigated to determine the gage to which the crane must be built and the amount of lateral float required in the crane.

d. Transferring from One Track System to Another. When cranes are transferred from one track system to another, float requirements must be determined and the running gear reconstructed as required to fit the new track system.

5. TRANSITION CURVE (INSIDE OR CONTROL CURVE). This transition curve is a series of compounding circular arcs, in which change of degree of curve is uniform and directly proportional to the flexible curve length. The first 20 feet of curvature of all transition curves is identical.

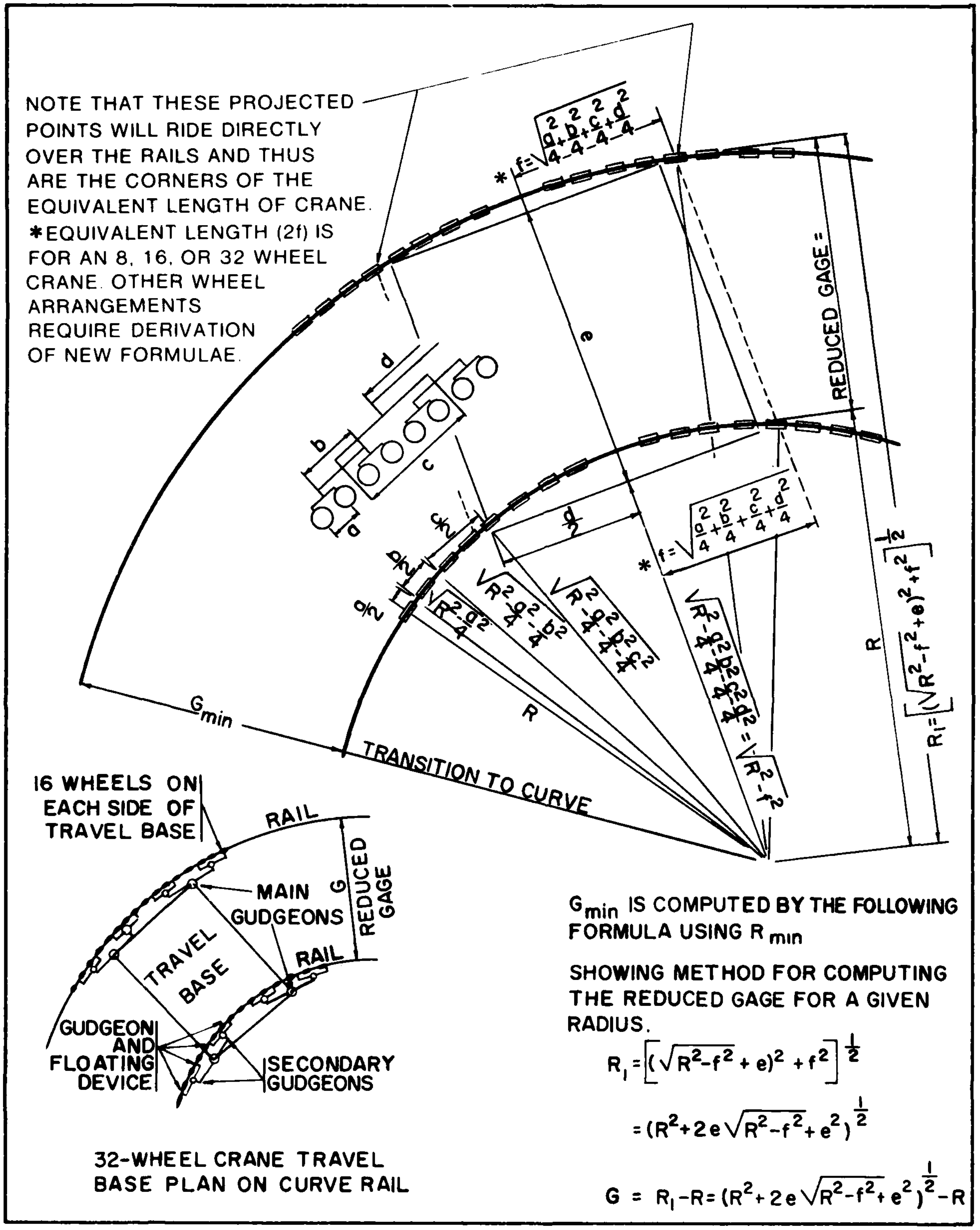

FIGURE 2
Gage Reduction Diagram
(32-Wheel Crane)

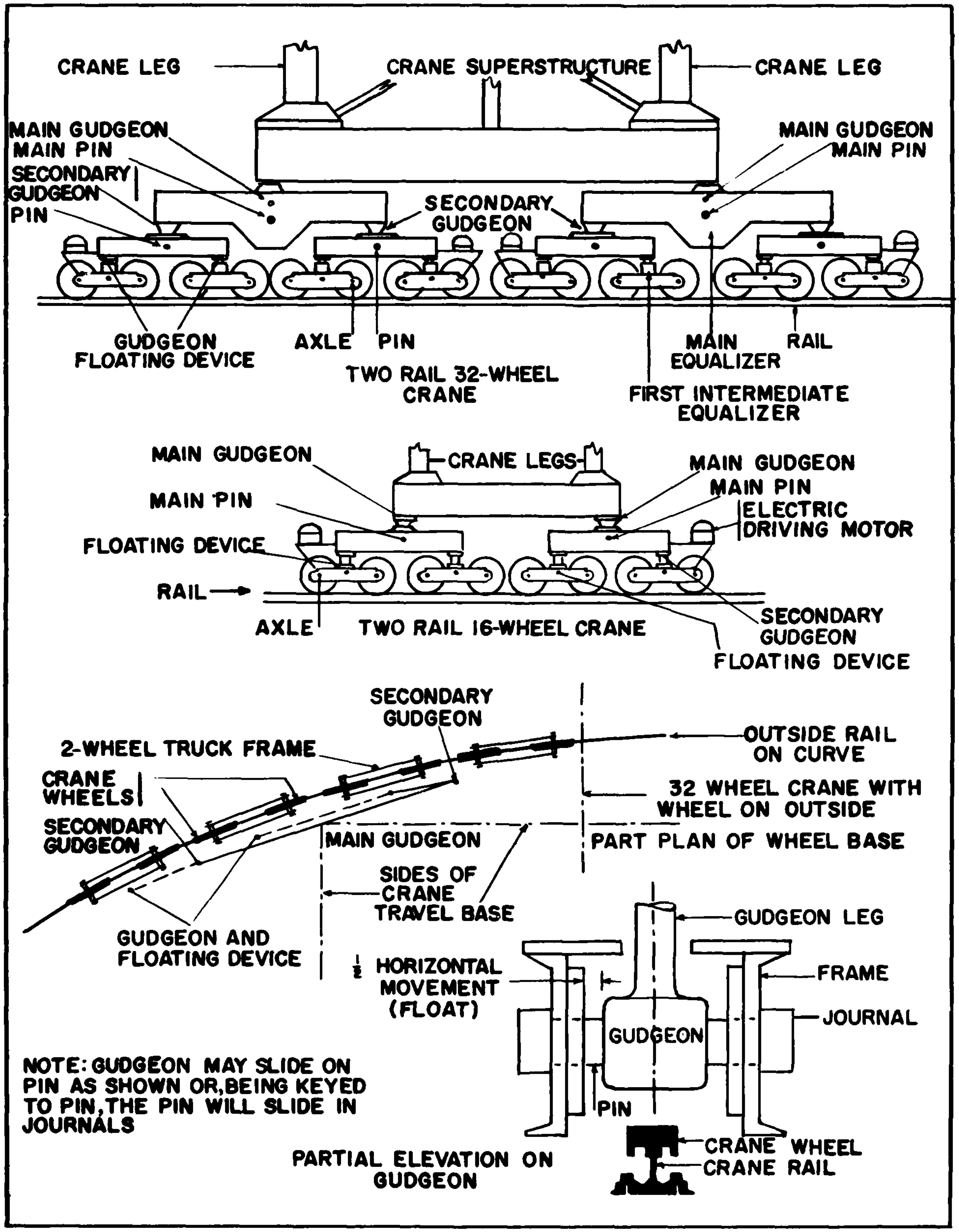

FIGURE 3
Travel Bases for Cranes

a. Gage Reduction. Although the actual reduction for a given radius may be computed precisely, the gradual reduction between tangent gage and reduced gage is an approximation.

6. SWITCH CURVE (INSIDE OR CONTROL CURVE). The first 20 feet of the transition curve, which is the switch curve, is an arc of constant radius of 300 feet. All switch curves, being identical, permit the standard switch to be inserted at the point of tangency of any curve design in accordance with these criteria, at any time (See Figure 4).

a. Switch Alinement. Although the body of the switch may project a few inches beyond the sharp end of the switch curve, the switch alinement will match precisely any designed flexible transition. Switching from curved track shall not be used unless the radius of the curve is greater than 300 feet and the turnout is to the outside of the curve, that is, not the center of the curve.

7. MAIN CIRCULAR CURVE (INNER). This curve is an arc of constant radius located between the beginning and ending transition curves (See Figure 5).

a. General Requirement. The general practice is to make an arbitrary choice of R_{min}, assuming R_{min} and R_C to be approximately equal. The curve which results from this choice of R_{min} must fit available space and other field conditions, and must not cause the available float of any crane using the track to be exceeded. Upon satisfying these conditions, R_C should normally be in the range:

$$R_C = R_{min} \pm 3.00 \text{ ft.}$$

Unless extreme space limitations dictate otherwise, it is desirable that neither R_{min} nor R_C be less than 80 feet.

b. Selection of Radius. The following are suggested methods for selecting R_{min} and R_C for use in the design procedure, Table 1.

(1) For a symmetrical curve with $\Delta = 180°$ (i.e. parallel tangents forming a "horse-shoe" curve), a first approximation of R_{min} should be:

$$R_{min} = 0.93M$$

The radius of the main circular curve is:

$$R_C = \frac{M-Y_C}{\cos\theta}$$

(2) For $90° \leq \Delta < 180°$, a recommended first approximation of R_{min} would be a value equal to one half the distance from PC to PT.

Note: The choice of R_{min} in this case is strictly an approximation. A certain amount of trial and error is involved in the final choice of R_{min}.

TABLE 1
Design Procedure

Description	Procedure	Reference
Equivalent length	Equivalent length of crane equals 2f where: $f = \sqrt{\frac{a^2}{4} + \frac{b^2}{4} + \frac{c^2}{4} + \frac{d^2}{4}}$ (8, 16, 32 wheel); $f = \sqrt{\frac{a^2}{4} + \frac{b^2}{6} + \frac{2c^2}{9} + \frac{d^2}{4}}$ (24 wheel)	Figure 2
Reduced gage (G_R)	For any circular curve, of a given radius R, where R is the radius of the inner rail: $G_R = (R^2 + 2e\sqrt{R^2 - f^2} + e^2)^{1/2} - R$ Notes: (1) Check to be certain that a gage reduction is not required for a 300-ft. radius, i.e., $G - G_R \leqq 1/2$ float of crane. (2) For two or more cranes, use the average equivalent length of the cranes to obtain the reduced gage, and check to ascertain that this gage reduction is within the float capability of each crane. If the gage reduction is too great for any crane, adjust the track design using the equivalent length of the critical crane until a satisfactory reduced gage is obtained.	Figures 2 and 3
Lateral float	Lateral float considerations: (a) $(e - G_R) \leqq 1/2$ (available lateral float). for a large radius curve, i.e., $R > 300$ ft. (b) $(G_{n1} - G_{n2}) \leqq 1/2$ (available lateral float). for any two points, not more than equivalent length of crane apart.	Par. 4 Figure 4
Inside or Control Curve		
Switch (fixed) curve	(1) Length of switch and number of compounding arcs $L_s = 20.00$ ft. $N_s = 1$ (2) Degree of curve and radius at both the T.S.C. and S.C.T. $R = 300.00$ ft. $D = 19° 5' 55''$ (3) Central angle $\theta_a = 3° 49' 11''$	Par. 5 Figures 4 and 5
Transition (flexible) curve	(1) R_{min}, as established in "Main Circular Curve". Notes: (1) For two-rail portal crane, the radius is to the centerline of the inside rail. (2) For four-rail portal crane, the radius is to the centerline of the inside track.	Par. 7 Figures 4 and 5
	(2) Number of intermediate arcs of equal length: N = 10 (may be changed if necessary)	Figures 4 and 5

TABLE 1 (Continued)
Design Procedure

Description	Procedure	Reference
Transition (flexible) curve (continued)	(3) Degree of curve and corresponding radius for an arc:	
	$D_n = D_{n-1} + \frac{(D_{max} - 19.0986^\circ)}{N}$	
	$R_n = \frac{5729.578}{D_n}$	
	Note: When $n = 1$, $D_o = D_s = 19.0986^\circ$	
	(4) Method of establishing length L_a	Figure 4
	Known e, f, F, and R_{min}	
	Where: F = 1/2 the maximum lateral float capability, in feet.	
	Note: Where the length of flexible transition (L_a) computed is greater than the space available, the length may be reduced by shortening the value of R_{min} in accordance with Section 3, paragraph 4b.	
	Determine: R_{2f} the radius at a point on the transition curve, 2f distance back from the TC.	
	Step (a) $G_{min} = (R^2_{min} + 2e\sqrt{R^2_{min} - f^2} + e^2)^{1/2} - R_{min}$	
	Step (b) $R_{2f} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$	
	Where: $a = 2e - F - 2G_{min}$	
	$b = e(2e - F - 2G_{min})$	
	$c = -ef^2$	
	Determine: L_a	
	Step (a) $D_{max} = \frac{5729.578}{R_{min}}$	
	$D_1 = D_s + \frac{D_{max} - 19.0986^\circ}{N}$, where $D_s = 19.0986^\circ$	
	$R_{max} = \frac{5729.578}{D_1}$	
	Step (b) $D_{2f} = \frac{5729.578}{R_{2f}}$	
	Step (c) $L_a = \frac{2f(D_{max} - D_1)}{D_{max} - D_{2f}}$	
	Notes: (1) L_a should be adjusted to the nearest foot to facilitate computations.	
	(2) Computation of L_a by this method leads to the probable satisfaction of the float considerations set forth in the first part of this table. To be sure that the float is fully satisfied, the design, when completed, should be checked by the NAVFAC TRACKS program to obtain an accurate calculation of the float.	

TABLE 1 (Continued)
Design Procedure

Description	Procedure	Reference
Transition (flexible) curve (continued)	(5) Arc length and central angle, corresponding with the degree of curve D_n for an arc (n): $$A_n = \frac{L_a}{N}$$ $$\Delta_n = \frac{A_n D_n}{100}$$ (6) The central angle from the T.S.C. to any P.C.C. is: $$\theta_n = \theta_{n-1} + \Delta_n \ldots \text{or} \ldots \theta_n = 3.8197^\circ + \frac{L_n - 20}{200}(D_1 + D_n)$$ Note: θ_n, X_n, and Y_n are used herein to designate angles and offset distances from the T.S.C. to the pints of compound curvature only. They are not used to designate angles or offsets to any arbitrary point on the transition curve. (7) The central angle of the flexible transition is: $$\theta_a = \theta - \theta_s \text{ or,}$$ $$\theta_a = \frac{L_a}{200}(D_1 + D_{max})$$ the coordinates for any P.C.C. are: $$X_n = X_{n-1} + R_n(\sin\theta_n - \sin\theta_{n-1})$$ $$Y_n = Y_{n-1} + R_n(\cos\theta_{n-1} - \cos\theta_n)$$	
Complete curve combination	The tangent distance for the complete curve is: $$T = X_c - (R_c \sin\theta) + (R_c \cos\theta + Y_c)\tan\frac{\Delta}{2}$$	Figure 5
<u>Outside Curve</u>		
Switch (fixed)	(1) This curve is identical with the switch curve (inside or control)	Figure 4
	(2) The lead is: $$t_s = G \sin 3^\circ\ 49'\ 11''$$	Figure 4 Par 10
Reduced gage (G_s)	G_s at the S.C.T., by convergence of outer and inner rails of switch curve is: $$G_s = G \cos 3^\circ\ 49'\ 11''$$	Figure 4
Transition (flexible) curve	(1) Radius and length of any arc $$R_n = G_s + \text{radius of corresponding arc of inner curve}$$ $$A_n = R_n\Delta_n \ (A_n \text{ in feet, } \Delta_n \text{ in radians})$$	Figure 4
	(2) Distance shifted back of the SCT along tangent t_s is: $$d = \frac{G_s - G_{min}}{\sin\theta_a}$$	Figure 4, Par 10

TABLE 1 (Continued)
Design Procedure

<table>
<tr><th>Description</th><th>Procedure</th><th>Reference</th></tr>
<tr><td>Transition (flexible) curve (continued)</td><td>(3) Tangent length between end of switch curve and beginning of flexible curve, and its offset distances in the W and Z directions are:

$t_1 = t_s - d$

W direction $= t_1 \cos 3° \, 49' \, 11''$

Z direction $= t_1 \sin 3° \, 49' \, 11''$

(4) Tangent length between end of flexible curve and main circular curve, and its offset distances in the W and Z directions are:

$t = \dfrac{G_s - G_{min}}{\tan \theta_a}$

W direction $= t \cos \theta$
Z direction $= t \sin \theta$

(5) The coordinates for any P.C.C. are:

$W_n = W_{n-1} + R_n (\sin \theta_n - \sin \theta_{n-1})$

$Z_n = Z_{n-1} + R_n (\cos \theta_{n-1} - \cos \theta_n)$

(6) The gage at any P.C.C. of the transition curve, back of R_{min} is:

$G_n = G_s - d \sin (\theta_n - \theta_s)$</td><td>Figure 4
Par 10</td></tr>
<tr><td><u>Main Circular Curve</u></td><td>The central angle is equal to:

$\Delta_c = \Delta - 2\theta$

Radius of inner main circular curve $= R_c$

Radius of outer main circular curve $= R_c + G_{min}$

Gage on main circular curve is G_{min}</td><td>Figures 4 and 5</td></tr>
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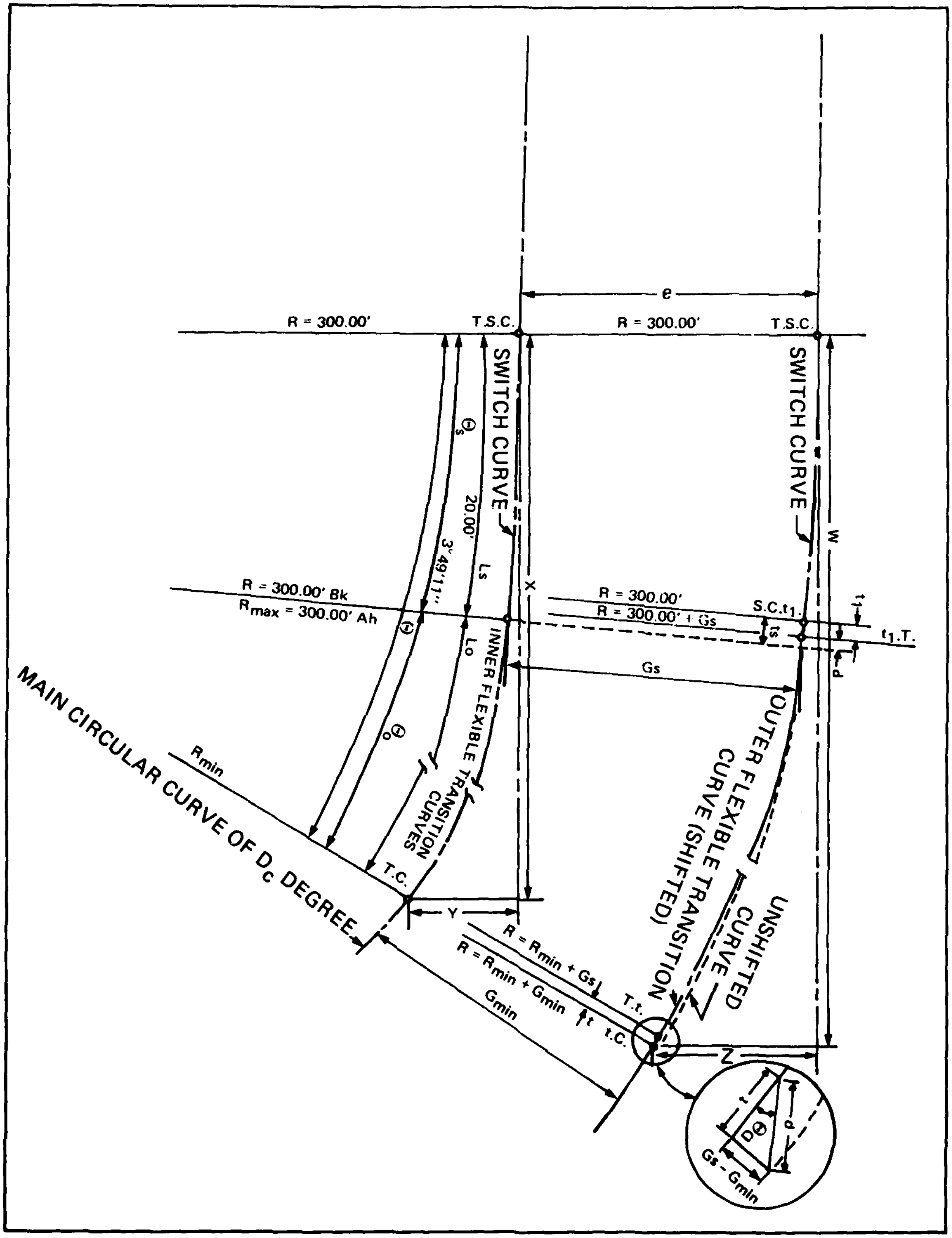

FIGURE 4
Relationship of Curves

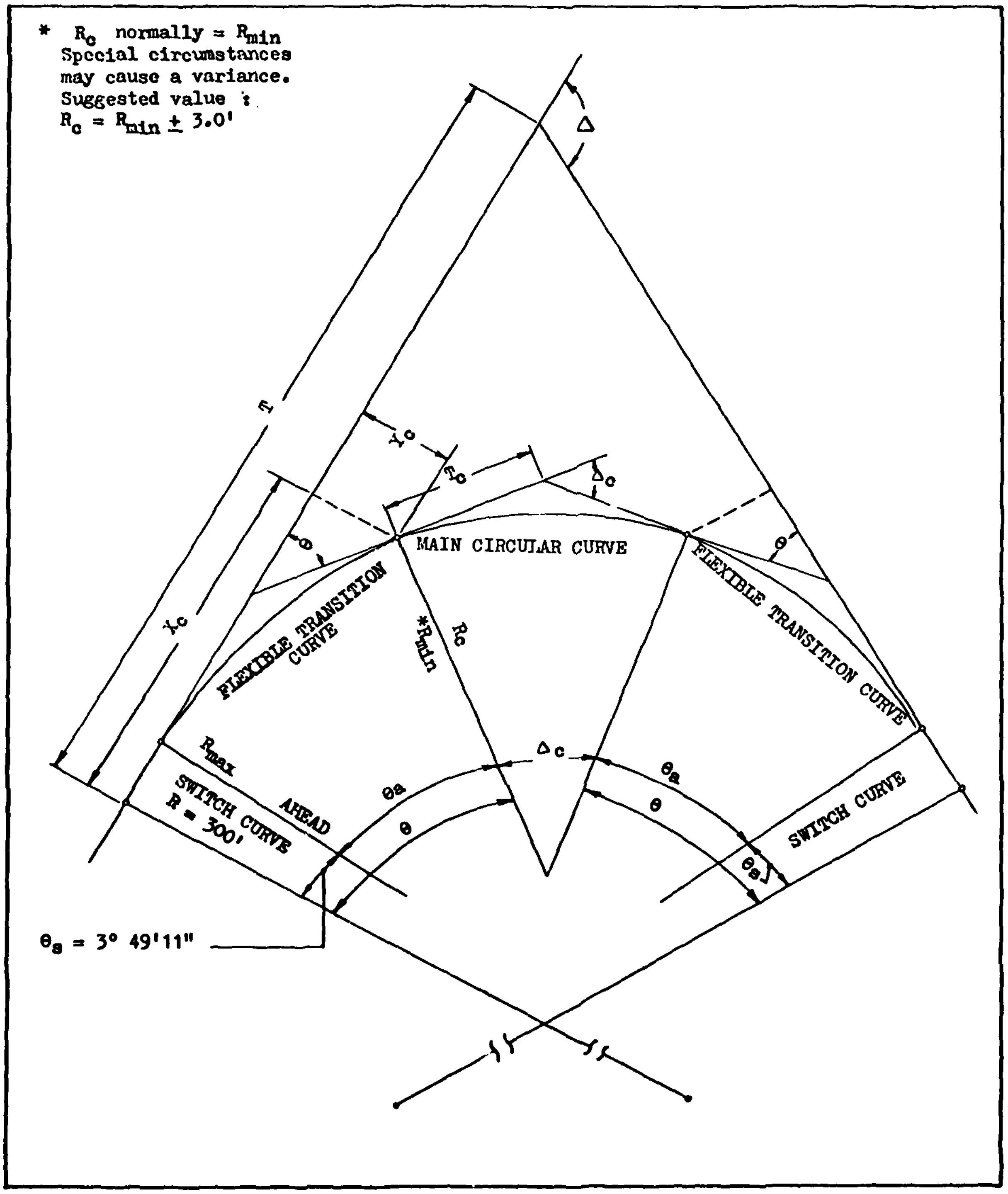

FIGURE 5
Functions of Inner or Control Curve

(3) For $\Delta < 90°$, it is recommended that the first trial should be based upon historical data of a similar curve if available. Otherwise, estimate and refine by trial and error.

$$\Delta, M, Y_C \text{ and } \theta = \text{(See Table 4)}.$$

8. COMPLETE CURVE COMBINATION. A complete curve combination consists of a minimum of two switch curves and two abutting transition curves, or a maximum of two switch curves and two transition curves, separated by one main circular curve (See Figure 5).

a. Transition Curve. When the main intersection angle (Δ) is 90 degrees or less, the curve may be made transitional throughout. When the curves are transitional throughout, the inner transition curves abut, but the outer transition curves are separated by a tangent of 2t length.

b. Tangent Length. Tangent length between curves of opposite direction shall be at least equal to the equivalent length of the crane.

9. REVERSE CURVE. Under no circumstances shall the commonly called "reverse curve" be used.

10. TRANSITION CURVE (OUTSIDE). This curve is a series of compounding circular arcs which are not concentric with the corresponding arcs of the inside transition curve. The first 20 feet of curvature of all transition curves shall be identical to permit the use of one switch design for all turn outs. The curve components are as follows:

a. Central Angle. The series of compound arcs comprising the outer flexible transition curve have the same central angle as the corresponding arc of the inside transition curve (See Figure 6).

b. Radii. The radii of the arcs of this transition are obtained by adding G_S to the radii of the inner flexible transition curve.

c. Gage Reduction. The required gage reduction through the flexible transition curve is obtained by shifting the outer curve back of the SCT along tangent t_S a distance d (See Figure 4).

d. Alinement Closure. A short tangent distance t_1 is then introduced between the end of the switch curve and the beginning of the outer flexible transition curve (see Figure 4). A short tangent distance is also introduced between the end of the flexible transition curve and the main circular curve (See Figure 4).

11. SWITCH CURVE (OUTSIDE). The outer switch curve, which is the first 20 feet of the transition curve, is an arc of constant radius of 300 feet. This switch curve is identical with that used for the first 20 feet of curvature on the inner alinement, permitting the standard switch to be inserted at the point of tangency of any curve at any time.

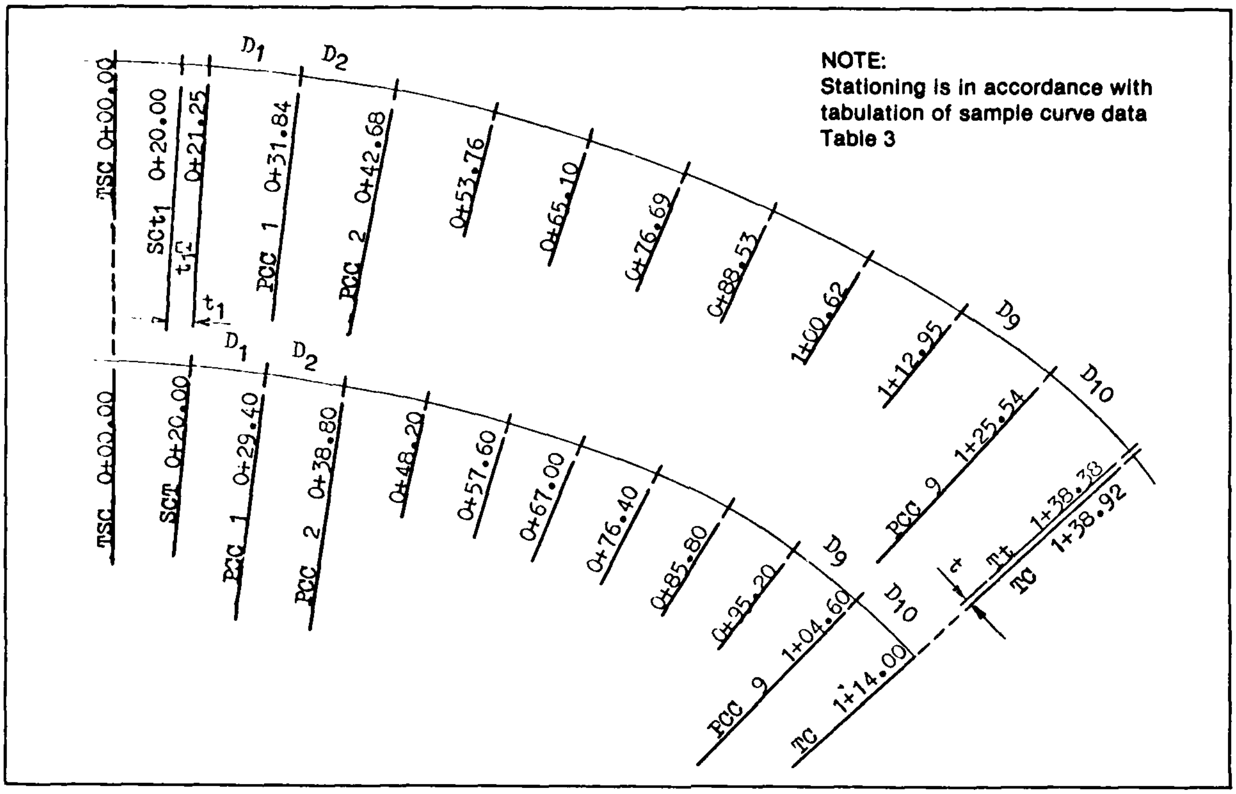

FIGURE 6
Relation Between Inner and Outer Curve Stationing and Transition Curve Arc Definition

a. Location. The point of beginning of the outer switch (fixed) curve is precisely located laterally opposite the point of beginning of the inner switch curve.

b. Convergence. The outer and inner switch curves being identical results in the outer curve converging on the inner curve. This convergence closely approximates the required gage reduction, so that a negligible amount of misalinement is introduced.

c. Lead. The inner and outer switch curves are not concentric. Therefore, a point radially opposite the forward end of the inner switch is ahead of the forward end of the outer switch curve. This distance is called the lead.

12. MAIN CIRCULAR CURVE (OUTSIDE). This curve is an arc of constant radius which is concentric with the corresponding inside main circular curve.

a. Central Angle. The outside main circular curve has the same central angle as the inside main circular curve.

b. Radius. The radius of this curve is obtained by adding G_{min} to the radius of the inside main circular curve (See Figure 4).

c. Gage Reduction. The gage on this curve is constant and equal to G_{min}.

13. DESIGN PROCEDURE. See Table 1 for procedures.

14. SAMPLE CURVE COMPUTATION. See Table 2 for example.

15. TABULATION OF SAMPLE CURVE COMPUTATION. See Table 3 for tabulation.

16. DRYDOCK HEAD-END. The following considerations are essential to design:

(1) Access connections shall not be made to a continuous circular curve connecting both sides of a drydock. In extreme cases where such connections are absolutely necessary, prior NAVFACENGCOM approval shall be obtained.

(2) The head-end curve is a special case of a complete curve combination (see paragraph 8, preceding, for description) in which a curve having a 180-degree central angle is required to connect two parallel tangent tracks.

(3) Where feasible, the design shall be such that the curve combination is symmetrical about a line equidistant between the parallel tangent tracks.

17. VERTICAL ALINEMENT. The following considerations are essential to design.

(1) Design horizontal curves for level grade in order to minimize the possibility of derailment, with the attendant danger of overturning.

(2) If there is an absolute necessity to use other than a level grade for a horizontal curve, approval must be obtained from NAVFACENGCOM HQ.

(3) Limited grades (maximum 1 percent) and vertical curves, shall be placed on tangent track only when it is necessary to connect parts of a track system constructed at different elevations.

(4) Nonlevel grade shall be minimum distance of the crane length (centerline to centerline of end wheels) from the commencement of any crossing, horizontal curve, or turnout.

(5) When nonlevel grade is permitted by NAVFACENGCOM HQ, use the formulas and procedure of the example in paragraph 17a, following, in determining vertical alinement.

a. Example of Vertical Alinement. A horizontally curved track should not be placed on other than level grade. Derailment, with attendant danger of overturning, is probable because of the following conditions.

TABLE 2
Sample Curve Composition

Item	Computation (partial)	Reference
Transition curve (inside or control):	<u>Given</u>: D_{min} = 19.0986 (end of switch curve) G = e = 30.000 ft. D_{max} = 70.0000° L_a = 94.000 ft. f = 18.820 ft. Average float capability of crane 0.50 ft. in either direction.	Figure 4
Number of arcs_____	N = 10	
Degree of arc No. 2	$D_2 = 24.1887 + \frac{70.000 - 19.0986}{10} = 29.2789$	
Degree of arc No. 3	$D_3 = 29.2789 + \frac{70.000 - 19.0986}{10} = 34.3690$	
Central angle arc No. 1	$\Delta_1 = \frac{9.4 \times 24.1887}{100} = 2.2737° = 2° 16' 25"$	
Central angle arc No. 2	$\Delta_2 = \frac{9.4 \times 29.2789}{100} = 2.7522° = 2° 45' 08"$	
Central angle to S.C.T.	$\theta_s = 3° 49' 11"$	Figures 4 and/or 5
θ_n for arcs to P.C.C. 1.	$\theta_1 = 3° 49' 11" + 2° 16' 25" = 6° 05' 36"$	
θ_n for arcs to P.C.C. 2.	$\theta_2 = 6° 05' 36" + 2° 45' 08" = 8° 50' 44"$	
Coordinates for P.C.C. 7.	$X_7 = 74.671 + 104.689 (\sin 29° 47' 02" - \sin 24° 38' 21") = 83.028$	
	$Y_7 = 13.121 + 104.689 (\cos 24° 38' 21" - \cos 29° 47' 02") = 17.418$	
Tangent distance for $\Delta = 120° 00' 00"$	$T = 104.986 - (81.851 \sin 48° 05' 18") + [(81.851 \cos 48° 05' 18" + 34.943) \tan 60° 00' 00"] = 199.280$	Figure 5
Transition Curve (outside):		
Lead t_s	$t_s = 30.000 \sin 3° 49' 11" = 1.999$ ft.	
Reduced gage	$G_s = 30.000 \cos 3° 49' 11" = 29.933$ ft.	Figures 2 and 4
	$G_{min} = (81.851^2 - 60\sqrt{81.851^2 - 18.820^2} + 30.000)^{1/2} - 81.851 = 29.410$ ft.	Figure 4
θ_a, Central angle of Flexible Transition Curve	$\theta_a = \frac{94.000}{200}(24.1887 + 70) = 44.2687 = 44° 16' 07"$	Figure 4
Distance shifted back of S.C.T.	$d = \frac{29.933 - 29.410}{\sin 44° 16' 07"} = 0.749$ ft.	Figure 4
Distance between end of transition and main curves	$t = \frac{29.933 - 29.410}{\tan 44° 16' 07"} = 0.537$ ft.	Figure 4

Notes: For complete design procedure see Table 1.
For all values for P.C.C. No. 1 through 9, see Table 3 and Figure 4.

TABLE 3
Tabulation of Sample Curve Composition

	Inner Curve													Outer Curve							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
	Control Point	Control Point Station	D_n Degrees	R_n Feet	Δ_n Degrees (Decimals)	Δ_n Degrees, Min., Sec.	θ_n	Sine θ_n	Sine θ_n Minus Sine θ_{n-1}	Cosine θ_n	Cosine θ_{n-1} Minus Cosine θ_n	Coordinates X Feet	Coordinates Y Feet	R_n Feet	Δ_n Radians	A Feet	Coordinates W Feet	Coordinates Z Feet	Control Point Station	Control Point	G_n (Feet)
Fixed Curve	T.S.C.	0 + 00.00										0.000	0.000				0.000	0.000	0 + 00.00	T.S.C.	
			19.0986	300.00										300.00							
			19.0986	300.00																	
	S.C.T.	0 + 20.00										19.985	0.666				19.985	0.666	0 + 20.00	S.C.t_1	
Flexible Transition Curve	S.C.T.	0 + 20.00					3° 49′ 11″	0.0666170		0.9977786		19.985	0.666			t_1 = 1.250				t_1 T	
			24.1887	236.870	2.2737	2° 16′ 25″			0.0395325		.0034284						21.232	0.749	0 + 21.25		
	P.C.C.	0 + 29.40					6° 05′ 36″	0.1361495		0.9943502		29.349	1.478	266.803	0.0396842	10.588					29.9033
			29.2789	195.690	2.7522	2° 45′ 08″			0.0476228		.0062439						31.779	1.664	0 + 31.84	P.C.C.	
	P.C.C.	0 + 38.80					8° 50′ 44″	0.1537723		0.9881063		38.668	2.700	225.623	0.0480352	10.838					29.8674
			34.3690	166.708	3.2307	3° 13′ 51″			0.0554418		.0102364						42.524	3.073	0 + 42.68	P.C.C.	
	P.C.C.	0 + 48.20					12° 04′ 35″	0.2092141		0.9778699		47.911	4.406	196.641	0.0563860	11.088					29.8254
			39.4592	145.203	3.7092	3° 42′ 33″			0.0628226		.0155830						53.426	5.086	0 + 53.76	P.C.C.	
	P.C.C.	0 + 57.60					15° 47′ 08″	0.2720367		0.9622869		57.033	6.669	175.136	0.0647370	11.338					29.7777
			44.5493	128.612	4.1876	4° 11′ 15″			0.0695422		.0224338						64.429	7.815	0 + 65.10	P.C.C.	
	P.C.C.	0 + 67.00					19° 58′ 23″	0.3415789		0.9398531		65.977	9.554	158.545	0.0730880	11.588					29.7246
			49.6394	115.424	4.6661	4° 39′ 58″			0.0753239		.0309020						75.454	11.372	0 + 76.69	P.C.C.	
	P.C.C.	0 + 76.40					24° 38′ 21″	0.4169028		0.9089511		74.671	13.121	145.357	0.0814389	11.838					29.6668
			54.7296	104.689	5.1446	5° 08′ 41″			0.0798258		.0410452						86.403	15.863	0 + 88 . 3	P.C.C.	
	P.C.C.	0 + 85.80					29° 47′ 02″	0.4967286		0.8679059		83.028	17.418	134.622	0.0897898	12.088					29.6051
			59.8197	95.781	5.6231	5° 37′ 23″			0.0826507		.0528479						97.149	21.390	1 + 00.62	P.C.C.	
	P.C.C.	0 + 95.20					35° 24′ 25″	0.5795793		0.8150580		90.944	22.480	125.714	0.0981416	12.338					29.5407
			64.9099	88.270	6.1015	6° 06′ 05″			0.0833505		.0661994						107.540	28.033	1 + 12.95	P.C.C.	
	P.C.C.	1 + 04.60					41° 30′ 30″	0.6627298		0.7488586		98.302	28.323	118.203	0.1064915	12.588					29.4751
			70.0000	81.851	6.5800	6° 34′ 48″			0.0814465		.0808754						117.392	35.858	1 + 25.54	P.C.C.	
	T.C.	1 + 14.00					48° 05′ 18″	0.7441765		0.6679832		104.968	34.943	111.784	0.1148128	12.838					29.4102
																	126.495	44.893	1 + 38.38	T.t	
																t = 0.537					
																	126.855	45.298	1 + 38.92	T.C.	

(1) Points on the rails directly under the corners of the crane traversing the curved track would be at different elevations and not in the same plane. Because the frame and legs are a rigid structure, the sills and girders cannot appreciably conform to other than a plane surface.

(2) In understanding the geometry of this problem, consider the crane as simply a rigid rectangular frame. The higher inside corner and the lower outside corner of this frame (always diagonally opposite) will remain on the rails at all times. Of the other two corners, the one nearer the center of gravity will be forced to the rail, thus suspending the fourth corner (diagonally opposite) above the rail by twice the amount of the difference in elevation at points on the rails under laterally opposite corners.

(3) An identical suspension occurs at the corresponding point on the sill of the actual crane traversing such track. The suspension of one truck above the rail will be the amount of suspension at the sill multiplied by N' where:

$$N' = \frac{\text{total number of pivot points (at one corner)} + 1}{2} \qquad (3)$$

$$N' = \frac{\text{total number of wheels of crane}}{8} \qquad (4)$$

(1) Application. The following hypothetical case illustrates the application of this procedure. From A of Figure 7:

$$\beta = \text{arc sin}\,\frac{18.8716}{100.00} \qquad (5)$$

$$\beta = 10^\circ\ 52'\ 40''$$

$$\phi = \text{arc sin}\,\frac{18.8716}{120.00} \qquad (6)$$

$$\phi = 9^\circ\ 02'\ 53''$$

$$\Delta_2 = \beta - \phi = 1^\circ\ 49'\ 47'' \qquad (7)$$

$$\text{Arc cb and arc ha} = (100.00)(\text{radian } 1^\circ\ 49'\ 47'') = 3.193 \text{ ft.} \qquad (8)$$

$$\Delta_1 = 2\phi = 18^\circ\ 05'\ 46'' \qquad (9)$$

$$\text{Arc bh} = (100.00)(\text{radian } 18^\circ\ 05'\ 46'') = 31.584 \text{ ft.} \qquad (10)$$

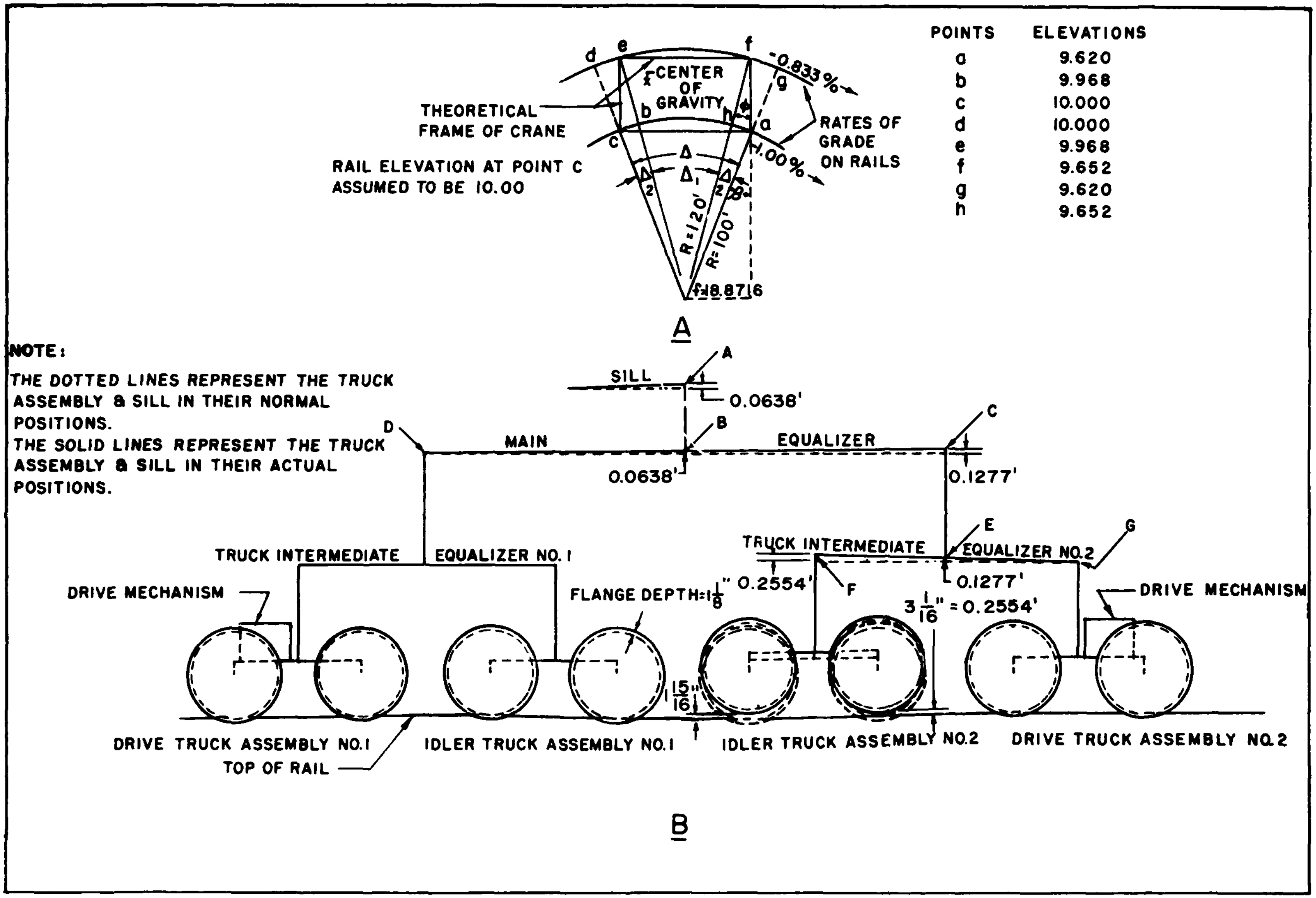

FIGURE 7
Crane Reaction to Grades on Horizontal Curves

(2) Suspension. The crane track is laid level, laterally. Therefore the difference of elevation between points c and b, or h and a, is 3.193 feet multiplied by 1.00 percent, which is equal to the difference between points c and e or a and f. See A of Figure 7 for the elevations of these points. Frame corner "a" is suspended 0.0319 feet multiplied by 2, and the sill at point A (of B of Figure 7) is suspended an identical amount, or 0.0638 feet. The suspension at point B, a pivot point, equals the suspension at point A. The truck intermediate equalizers, in all probability, are not exactly balanced; therefore, assume point D descends and point C rises.

(3) Vertical Position. The vertical position of point C is now 0.1277 feet above normal; it follows that point E is the same amount above normal. The drive truck assembly No. 2 being heavier than the idler truck assembly No. 2, the point F will rise 0.1277 feet above point E. Point F will now be 0.2554 feet above point G, the normal position. The flange is 1-1/8 inches in depth, which leaves a clearance (3-1/16 - 1-1/8) = 1-15/16 inches between the top of the rail and the flange on each wheel of idler truck assembly No.2, assuming that the idler truck assembly remains balanced because of friction. This clearance will permit the truck assembly to swivel and cause derailment. Distance (S) of the wheels of one truck assembly above the rail is determined by:

$$S = R\left[\text{radian}\left(\text{arc sin}\,\frac{f}{R} - \text{arc sin}\,\frac{f}{R_1}\right)\right](g)\left[\frac{w}{4}\right] \tag{11}$$

in which g is the rate of grade on the inside rail, and w is the total number of wheels.

Given: $R = 100$, $R_1 = 120$, $f = 18.87$, $g = 1.00\%$, $w = 32$ (from equation (11))

$S = 100$ (radian 1° 49' 47")(0.01)(8)

$= 0.2554$ or 3-1/16"

(4) <u>Balance</u>. If the wheels or idler truck assembly No. 2 do not remain balanced, which is the most likely condition, the distance (S) which one wheel, or pair of wheels, will be above the rail is twice the amount shown by equation (11) and the formula for the worst, most likely condition will be:

$$S = 2R\left[\text{radian}\left(\text{arc sin}\,\frac{f}{R} - \text{arc sin}\,\frac{f}{R}\right)\right](g)\left[\frac{w}{4}\right] \tag{12}$$

18. **SYMBOLS AND NOMENCLATURE.** In the calculation of portal crane track alinement, there are many special symbols used; for a list of these symbols, see Table 4.

TABLE 4
Symbols and Nomenclature

Symbol	Definition
G	Nominal track gage on tangent track, centerline to centerline of rail of a two-rail-system or centerline to centerline of track of a four-rail-system.
G_n	Gage at any P.C.C. of Transition Curve.
G_R	Reduced gage for a given radius.
G_s	Reduced gage at S.C.T.
G_{min}	Reduced gage at P.C.T. or T.C.
g	Rate of grade of inside rail.
f	One half equivalent length of crane.
e	Crane gage (also normally tangent track gage).
Float	Lateral movement of crane tracks.
F	One-half maximum lateral float capability, where maximum float equals sum of float in either direction.
T.S.C.	Point of Tangent to Switch (fixed) Curve.
S.C.T.	End of Switch Curve and beginning of Flexible Transition Curve (on inner alinement).
P.C.C.	Point of Compound Curvature (common point of any two successive circular arcs of transition).
P.C.T.	Point of Compound Transition (on inner alinement where no main circular curve is employed).
T.C.	End of Transition Curve (point of Transition Curve to main circular curve).
t_s	Length of lead of inner Switch Curve over outer Switch Curve.
t_1	Short tangent length between outer Switch Curve and outer Flexible Transition Curve.
t	Short tangent length between sharp end of outer Transition Curve and beginning of outer main circular curve.
S.C.t_1	End of outer switch curve and beginning of of tangent t_1.
t_1.T	End of tangent t_1 and beginning of outer Flexible Transition Curve.
T.t	End of outer Flexible Transition Curve and beginning of tangent t.
t.C.	End of tangent t and beginning of main circular curve (on outer alinement).
t.t.	Point of tangent to tangent (outer alinement where no main circular curve is employed).
D	Degree of curve (central angle subtended by arc of 100 ft).
D_{min}	Degree of curve at the end of the Switch Curve.
D_{max}	Degree of curve at T.C.
D_n	Degree of curve at any arc of the Transition Curve.

Symbol	Definition
d	Distance of shift of outer transition curve along tangent at S.C.T. to achieve reduced gage at circular curve.
D_c	Degree of curve of main circular curve.
R_{max}	Radius of flattest arc of Flexible Transition Curve.
R_{min}	Radius of sharpest arc of Flexible Transition Curve.
R_c	Radius of main circular curve.
R_s	Radius of switch curve (300′ constant).
L_s	Length of switch curve (20.00 ft.).
L_a	Length of Flexible Transition Curve.
L	Length of Transition Curve (total length of Switch Curve and Flexible Transition Curve).
L_n	Length along Transition Curve from T.S.C. to any P.C.C.
A_s	Length of arc of Fixed Transition Curve (Switch Curve).
A_n	Length of arcs of Flexible Transition Curve.
Δ_n	Central angle of circular arcs of Flexible Transition Curve.
Δ	Intersection angle of main control tangents.
Δ_c	Central angle of main circular curve.
θ_s	Central angle of switch curve (3° 49′ 11″).
θ_n	Central angle from T.S.C. to any P.C.C.
θ_a	Central angle of Flexible Transition Curve (S.C.T. to T.C.).
θ	Central angle from T.S.C. to T.C.
M	One half the distance between the parallel tangent tracks.
N	Number of Arcs of Transition Curve Constant (Eq 3 and 4).
n	Any point of Compound Curvature.
X	X-coordinate to point n on inner curve.
X_c	X-coordinate to T.C.
Y	Y-coordinate to point n on inner curve.
Y_c	Y-coordinate to T.C.
W	X-coordinate to point n on outer curve.
w	Total number of wheels of crane.
Z	Y-coordinate to point n on outer curve.
PI_a	Point of intersection of main control tangents.
PI_c	Point of intersection of main circular curve tangents.
T	Tangent distance from PI_a to T.S.C.
T_c	Tangent distance from PI_c to T.C.
S	Crane wheel suspension (Eq 11 and 12).

All dimensions are given in feet, except angles are in degree - minutes - seconds.

Section 4. PORTAL CRANE TRACK REPLACEMENT CURVE ALINEMENT

1. GUIDANCE. NAVFACENGCOM HQ has a computer program system and the accompanying documentation and application manuals, entitled TRACKS, available for use on the NAVFAC Computer Network for replacement track curve alinement. Although it is not mandatory to use this program for replacement design, its use is highly recommended due to its speed, accuracy and cost effectiveness. Since this program will play an important role in most track rehabilitation, the criteria of this section will be guided by the information needs of the computer procedure. For information and assistance in the use of the TRACKS program, contact NAVFACENGCOM HQ.

2. SURVEY REQUIREMENTS. For all replacement track design, where the existing foundation is to be reused, the following survey tolerances are required.

a. Transit and Distance Measurement Tolerance. Transit and distance measurement survey to locate the centerline of the existing track should be made to the closest .005 foot for distances and 20 seconds for angles. The centerline of rail for a four-rail system shall be the centerline of standard gage, while the centerline of rail for the two-rail system shall be the centerline of each rail. If it is the intent to utilize the TRACKS program, the survey data should include for inner and outer rail: delta angle, deflection angles to, and chord lengths between points about 5 feet apart along the existing track. Control points should be made permanent to last at least 2 years.

b. Dig-Up Survey Measurement Tolerance. Dig-up survey, to locate the centerline of the existing track in relation to the centerline of the existing foundations, should be made at locations spaced at 15-to 25-foot intervals along the curve. The actual number of dig-up locations is determined by the type of curve and by the matching relationship of the rail and foundation centerlines.

3. FOUNDATION STRUCTURAL ANALYSIS REQUIREMENTS. A structural analysis shall be made of the track foundation, for eccentricity, by the responsible structural authority. This analysis shall produce maximum allowable distances that the track centerline may be offset from the foundation centerline. These allowable eccentricities shall not be exceeded by the replacement track design without express approval of the cognizant NAVFACENGCOM Field Division.

4. REPLACEMENT TRACK DESIGN REQUIREMENTS. A replacement alinement design shall be made of inner and outer rails in accordance with the pertinent criteria of this chapter and, if the TRACKS computer program is used, with the Application Manual for Portal Crane Track Design and the TRACKS Users Manual. This design shall include proper mathematical steps and adequate checks to insure that the following criteria are satisfied:

a. <u>Deviations</u>. Deviations of design alinement from centerline of existing foundations shall not exceed the allowable structural eccentricities. Deviations of 1 inch or less can generally be achieved.

b. <u>Offset Closures</u>. Offset closures (i.e. the perpendicular distance from the surveyed curve tangent to the design curve tangent, at the design PT) must be 0.2 inch or less. For sketches see Application Manual or TRACKS Users Manual.

c. <u>Tangent Closures</u>. Tangent closures at the midpoint of the two partial curves making up a horseshoe curve must not be overlapping. (Tangent closure and horseshoe curves are described in detail in the Application Manual and the TRACKS Users Manual.) Overlapping tangent closures indicate that the two partial curves have no common point of tangency.

d. <u>Required Float</u>. Required crane float shall not exceed the allowable float for any crane that will traverse the track.

e. <u>Design Gage</u>. Design gage between rails shall be used as a check of field placement of track.

f. <u>Physical Obstructions</u>. Physical obstructions must be checked before allowing a new crane on the track.

5. RAIL CONSTRUCTION REQUIREMENTS. Prior to any portal crane track curve construction, all float requirements of portal cranes traversing the design curve must be satisfied. Working drawings showing adequate information for rail fabrication shall be prepared. These drawings should be formal, scaled layouts of the track alinement and should contain the following design information as a minimum:

a. Tangent lengths

b. PC, PT, and PI locations

c. For each segment

(1) Tangent offsets to segment PCC points

(2) Delta angles

(3) Radii

(4) Arc Lengths

(5) Stations of PCC's

(6) Gages

This information is necessary for working drawings for trackage described in Section 3 as well. The field survey made for replacement track design shall establish reference marks for the placement of rails. Rails shall be placed within $\pm$ 1/4 inch of the designed rail centerline alinement. Track gage shall be within $\pm$ 1/2 inch of the designed gage. Placement methods shall be such as to not cause kinks or other sharp changes in the smooth curvature of the rails.

REFERENCES

1. AAR Specifications for Design, Fabrication and Construction of Freight Cars, Volume 1. Association of American Railroads; Mechanical Division, 39 East Van Buren Street, Chicago, IL 60605.

2. Application Manual for Portal Crane Track Design, TRACKS computer program; Headquarters, Naval Facilities Engineering Command, 200 Stovall Street, Alexandria, VA 22332.

3. AREA Manual, American Railway Engineering Association; 2000 L Street, N.W., Washington, DC 20036.

4. AREA Portofolio of Trackwork Plans, American Railway Engineering Association; 2000 L Street, N.W., Washington, DC 20036.

5. Definitive Designs for Naval Shore Facilities, NAVFAC P-272; U.S. Naval Publications and Forms Center, 5801 Tabor Ave., Philadelphia, PA 19120.

6. Drainage Systems, NAVFAC DM-5.3; U.S. Naval Publications and Forms Center, 5801 Tabor Ave., Philadelphia, PA 19120.

7. Federal Specifications; available at U.S. Naval Publications and Forms Center, 5801 Tabor Ave., Philadelphia, PA 19120.

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8. Hydrology and Hydraulics, NAVFAC DM-5.2; U.S. Naval Publications and Forms Center, 5801 Tabor Ave., Philadelphia, PA 19120.

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13. TRACKS Users Manual, TRACKS computer program; Headquarters, Naval Facilities Engineering Command, 200 Stovall Street, Alexandria, VA 22332.

14. Track Safety Standards, Federal Railroad Administration, U.S. Department of Transportation; 400 Seventh Street, S.W., Washington, DC 20590

15. Weight Handling Equipment and Service Craft, NAVFAC DM-38; U.S. Naval Publications and Forms Center, 5801 Tabor Ave., Philadelphia, PA 19120.